TARGETS: A PERSPECTIVE FROM THE TECHNICAL AND COMMERCIAL POINT OF VIEW

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Prepared by Marcelo Salvatore & Carlos Pavón
Nuclear Division
salvator@invap.com.ar
capavon@invap.com.ar
EMPLOYEES

1000
(85% professionals and technicians)

400 Contractors

SALES

+ $ 200 M USD / YEAR

BACKLOG

$ 500 M USD

NEW CONTRACTS

$ 700 M USD
Introduction: Design Principles & Considerations

Comparison with Fuel Plates

Reflections on Quality Requirements

Operational / Irradiation Differences

Potential Alternatives: Design / Manufacturing Changes & Implications

A Way Forward, Ideas for consideration

Commercial Situation: comments on present demand & supply

Alternatives

Final Comments
Mo 99 Total Production Requirements + Plate / Target Characteristics + Reactor Core Characteristics + Safety Considerations = Final Irradiation Rig Design

Target Parameters: frozen today!

Only Place for Design Optimization!
Since their conception, molybdenum production targets have been fabricated following “extremely similar” design criteria used for MTR fuel plates (except for adjustments to optimize the transportation to the processing plant and some requirements related to their chemical processing).

<table>
<thead>
<tr>
<th>Parameters / Comparison</th>
<th>Fuel Plate</th>
<th>Mo Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrichment [%U-235]</td>
<td>19.75</td>
<td>19.75</td>
</tr>
<tr>
<td>Plate thickness [mm]</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Meat thickness [mm]</td>
<td>0.71</td>
<td>0.70</td>
</tr>
<tr>
<td>Meat width [mm]</td>
<td>65.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Meat composition</td>
<td>U₃Si₂-Al</td>
<td>UAIₓ-Al</td>
</tr>
<tr>
<td>Uranium density in meat [g/cm³]</td>
<td>4.8</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Comparison with fuel plates - II

In the last 12-15 years a transition from HEU to LEU based Moly 99 production became a must, leading to the current production plates geometry and composition.

<table>
<thead>
<tr>
<th></th>
<th>HEU - Target</th>
<th>LEU - target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrichment [%U-235]</td>
<td>90</td>
<td>19.75</td>
</tr>
<tr>
<td>U235 content [g]</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Total U content [g]</td>
<td>1.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Total U density [g/cm³]</td>
<td>0.58</td>
<td>~3.0</td>
</tr>
<tr>
<td>U235 density [g/cm³]</td>
<td>0.53</td>
<td>~0.6</td>
</tr>
<tr>
<td>Clad material</td>
<td>Al 99.5%</td>
<td>Al 6061 or similar</td>
</tr>
</tbody>
</table>
Reflections on quality requirements - I

Standards from ASTM, ANSI or EPRI are employed in areas:

- Aluminum Sheet and Plate
- Metal Powder
- Uranium Quality
- Boron Content
- Aluminum / Frame Welding
- Utilization of commercial grade items in nuclear applications
Reflections on quality requirements - II

Others Design / Construction areas have no reference standards and so must be established by the Target Designer / Manufacturer:

- Design / Assembly Drawings
- Material Specifications
- Characterization and production of the uranium powder ($U_3O_8$, $UAl_x$-$Al$, etc.)
- Fabrication Procedures & Acceptance Criteria
- Corrosion Limits
- Fuel Qualification Program / PIE
- Quality Controls
Fuel plates and Molybdenum targets differ greatly in their irradiation programs within the core.

<table>
<thead>
<tr>
<th>Fuel Plate</th>
<th>Mo Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 60</td>
<td>Residence Time [FPd]</td>
</tr>
<tr>
<td>45 – 60</td>
<td>Burn Up [% U-235]</td>
</tr>
</tbody>
</table>

This differences allow us to infer that many of the limitations imposed on the fuel are too restrictive i.e. **there must be some room for relaxing and reducing margins**
Potential Alternatives: Design / Manufacturing Changes & Implications

A simple method to improve the Molybdenum production is to increase the uranium content through:

- An increase in the uranium density inside the target “meat”
- A decrease in cladding thickness

Seven cases were simulated & analyzed.

<table>
<thead>
<tr>
<th>Case</th>
<th>U Density [g/cm³]</th>
<th>Wall thickness [um]</th>
<th>U-235 content [g]</th>
<th>Increment [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.0</td>
<td>350</td>
<td>1.45</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>3.1</td>
<td>350</td>
<td>1.50</td>
<td>3.33</td>
</tr>
<tr>
<td>3</td>
<td>3.2</td>
<td>350</td>
<td>1.55</td>
<td>6.67</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
<td>350</td>
<td>1.59</td>
<td>10.00</td>
</tr>
<tr>
<td>5</td>
<td>3.0</td>
<td>200</td>
<td>2.07</td>
<td>42.86</td>
</tr>
<tr>
<td>6</td>
<td>3.0</td>
<td>100</td>
<td>2.48</td>
<td>71.43</td>
</tr>
<tr>
<td>7</td>
<td>3.3</td>
<td>100</td>
<td>2.73</td>
<td>88.57</td>
</tr>
</tbody>
</table>
Potential Alternatives: Design / Manufacturing Changes & Implications

- Design / Manufacturing Changes & Implications

Activity post irradiation [AU]

U Density [g/cm³]

Original target
Density increase

Wall thickness [g/cm³]

Original target
Wall decrease
The achieved increment in the target heat load leads to a slightly larger decay time in order to maintain safety margins for target transfer in air.

<table>
<thead>
<tr>
<th>Case</th>
<th>Activity post irradiation [AU]</th>
<th>Increment [%]</th>
<th>Activity after decay (AU)</th>
<th>Increment [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>107</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>109</td>
<td>1.9</td>
<td>102</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>111</td>
<td>3.8</td>
<td>103</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>113</td>
<td>5.6</td>
<td>105</td>
<td>4.7</td>
</tr>
<tr>
<td>5</td>
<td>130</td>
<td>21.7</td>
<td>117</td>
<td>17.2</td>
</tr>
<tr>
<td>6</td>
<td>143</td>
<td>33.8</td>
<td>126</td>
<td>26.2</td>
</tr>
<tr>
<td>7</td>
<td>150</td>
<td>40.4</td>
<td>131</td>
<td>30.9</td>
</tr>
</tbody>
</table>
Potential Alternatives: Design / Manufacturing Changes & Implications

- Activity after decay [AU]
- U-235 content [g]

- Original target
- Density increase
- Wall decrease
- Both modifications
A Way Forward, Ideas for consideration

**THE EVOLUTIONARY APPROACH**

With minor changes in the target plate design a great benefit can be attained

- +40% increment in activity post irradiation.
- 30% increment in activity after decay.
A Way Forward, Ideas for consideration

MAXIMIZE MOLY 99 OUTPUT FROM LEU TARGETS
- PROGRAM GOALS
- REQUIREMENTS
- GUIDELINES / STANDARDS
- SAFETY & LICENSING REQUIREMENTS
- REGULATOR ENGAGEMENT

OPTIMIZE DESIGN (FACILITY SPECIFIC)
- SELECT FACILITY
- OPTIMIZE RIG
- OPTIMIZE TARGET
- NARROW MARGINS

QUALIFY OPTIMIZED TARGET (AND SUPPLIER)
- IRRADIATION & QUALIFICATION PROGRAM
- PIE
- REGULATORY APPROVALS

OBTAIN STATISTICS AND IMPLEMENT CHANGE
Targets: Commercial Situation

Raw Material - Uranium
Uranium Enrichment
Target Manufacturing
Irradiation Installation - Research Reactor
Processing Plant - Radiisotope Purification
Radiopharmaceutical Plant
Commercialization - Logistics Chain
Hospitals / Patient

Waste Mng

Regulatory Framework
Nuclear & Human Health

NOT TOO MANY QUALIFIED SUPPLIERS (HEU or LEU)
NOT REAL COMPETITION
WHAT IF:
- A supplier faces a licensing problem
- A supplier faces an incident / accident that leads to production stops
- A supplier becomes too expensive or in practical terms a monopoly
Final Comments / Conclusions

• There is room for optimization in present LEU target design & manufacturing

• We propose improvements based on an Evolutionary approach

• Added Value: much less Al is involved in the Moly processing!!!

• A Development Program could be relatively simple & affordable

• INVAP is discussing w/CNEA a potential action plan in this regard

• There are User Acceptance & Regulator Risks

• On the commercial side the Moly 99 supply chain needs diversification with targets manufacturing & supply
Thank You

and

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salvator@invap.com.ar
WWW.INVAP.COM.AR

AV. CMTE. LUIS PIEDRABUENA 4950
(R8403AMU) SAN CARLOS DE BARiloCHE
RÍO NEGRO | PATAGONIA | ARGENTINA

TEL.: 54 (294) 440 9300
FAX: 54 (294) 440 9339

E-MAIL: INFO@INVAP.COM.AR
S 41°7'25 / O 71°14'35"